Irrigation Efficiency Under Deficit Irrigation & On-farm Water Budgets

ESHMC 31 March/1 April 2009

B. Contor

General Agreement:

- Deficit irrigation reduces ET
- This reduction must be considered in recharge calculation or else recharge will be too low/net extraction too high
- Recharge Tool explicitly addresses chronic deficit irrigation but not acute deficits
- ESPAM2 needs a more objective and repeatable method than ad-hoc adjustment of ESPAM1.1

Greg's Questions (e-mail last week)

- 1. "Should the farm-budget calculations be performed seasonally as in the current tool... or should the farm-budget calculations be performed monthly?"
- 2. "What methodology should be used... in the farm budget calculations?"
- 3. "Should the farm budget calculations include... soil moisture storage?"
- 4. "How do mods. to the farm budget calculations relate to... return flows?"

Compare Five Approaches

- Sullivan
- ESPAM w/o adjustment for acute deficit irrigation
- ESPAM1.1 *aka ESPAM(a)*
- ESPAM modified *aka ESPAM(b)*
- Martin-Supalla adjustment to ESPAM
- Fixed irrigation efficiency

We will discuss Willem's approach
later under the heading
"Calculating Returns as a Residual"

Proposed Criteria

- Consistent w/ theory & literature
  - efficiency vs. adequacy
- Consistent w/ conceptual expectations
  - percolation vs. diversion depth
  - ET vs. diversion depth
- Ability to adhere to delivery schedule & budget

Summary of Literature Findings

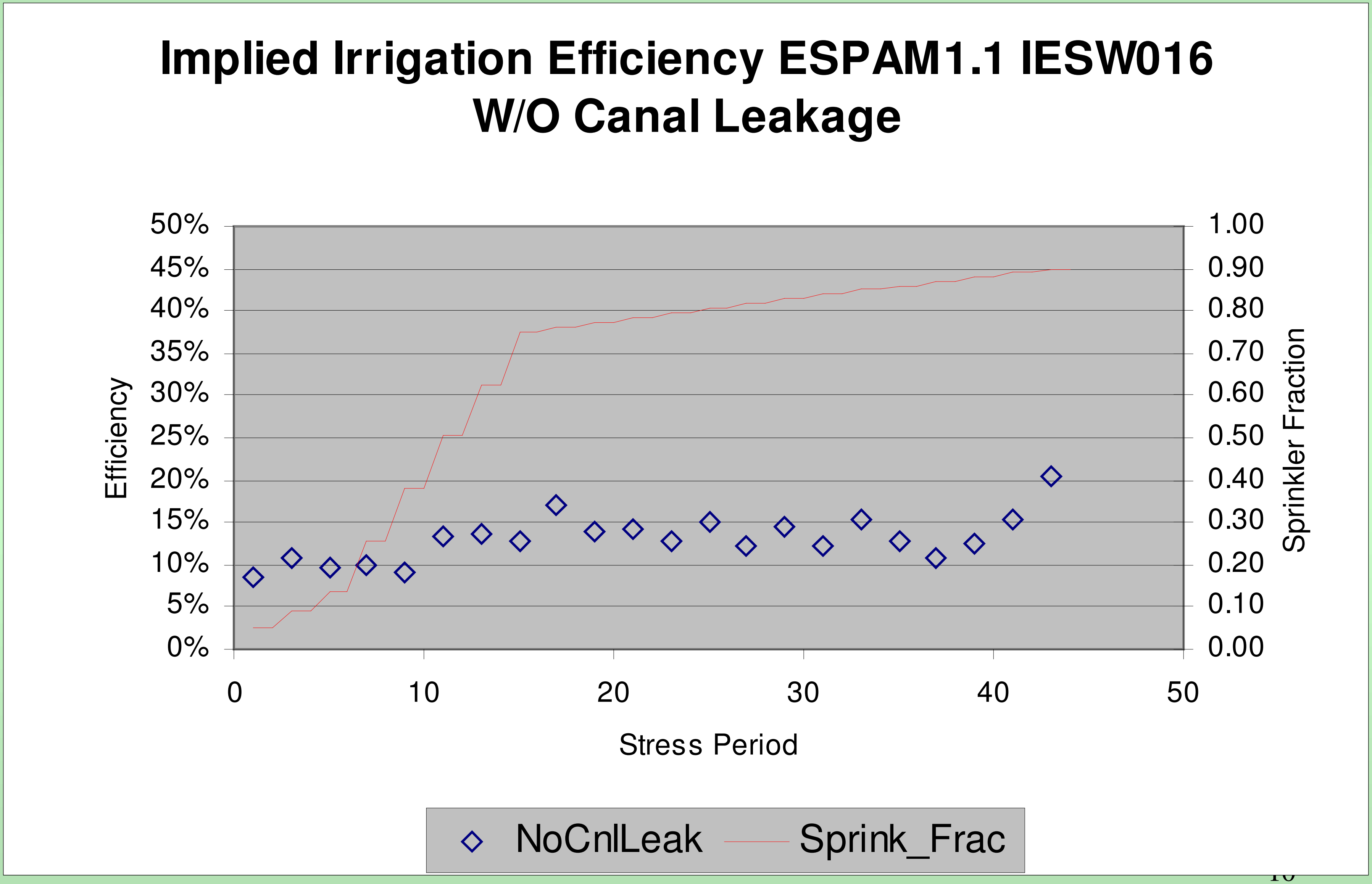
- Efficiency & Adequacy:
  - Efficiency monotonically increases as adequacy declines
  - Theoretical upper limit of efficiency ~ 100%
  - Observed efficiencies approach theoretical

Conceptual Expectations

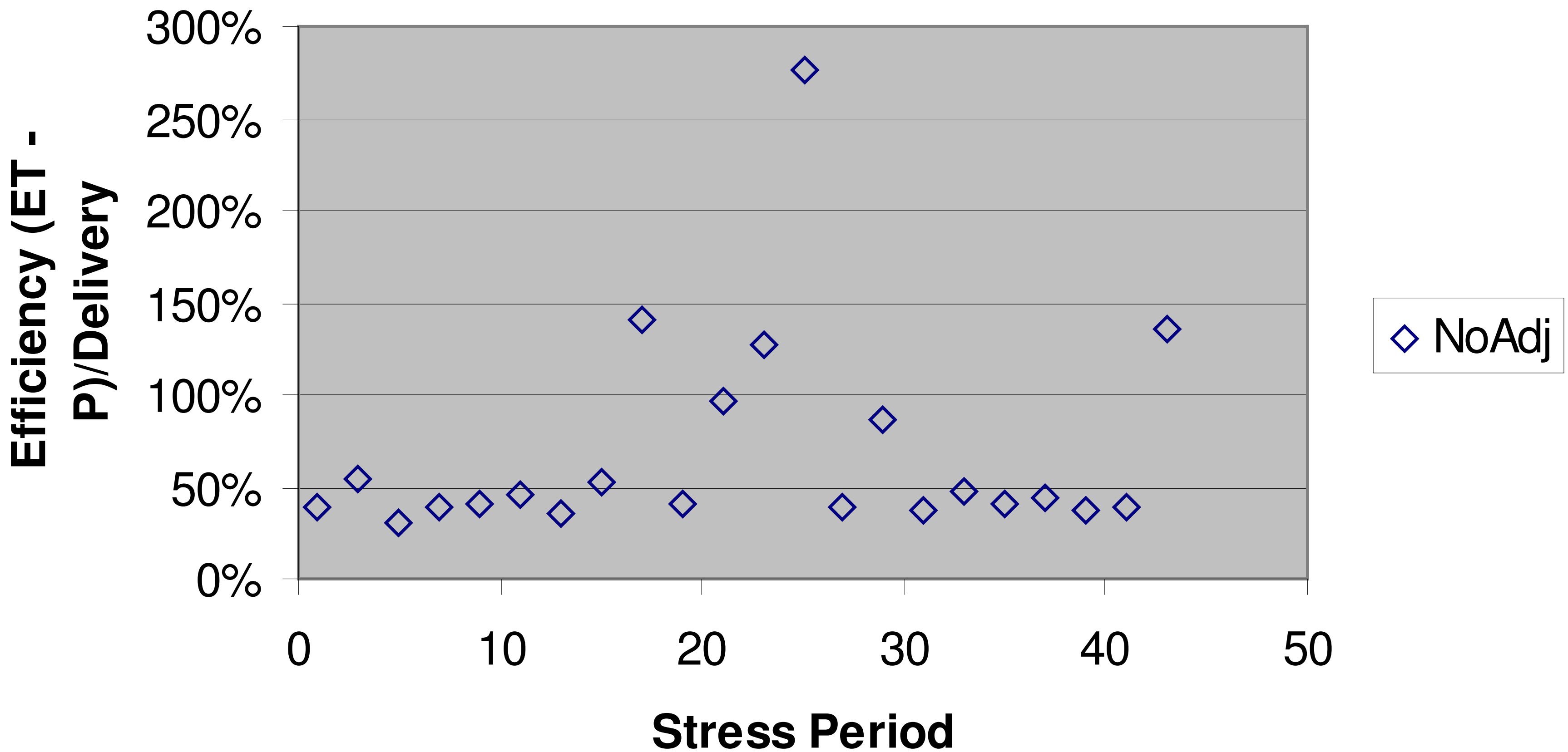
- Percolation & diversion depth:
  - zero < percolation < (diversions + ET)
  - monotonically increasing percolation w/ increasing diversion depth
- ET & diversion depth:
  - zero < ET < (diversions + precip)
  - max. ET limited by available energy
  - monotonically increasing ET w/ increasing diversion depth *(within reasonable range of depths)*

ESPAM w/o Adjustment *(never used; presented for illustration)*

- Recharge = (Precip + Div - Return - Canal - ET*Adj)
- No constraints; negative percolation is possible on SW-only parcels
- Two examples follow


Implied Irrigation Efficiency ESPAM1.1 IESW016
W/O Canal Leakage
Efficiency
Sprinkler Fraction
Stress Period
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
0
10
20
30
40
50
NoCnlLeak
Sprink_Frac

Implied Irrigation Efficiency ESPAM1.1 IESW054 (ignoring deficit adjustment)

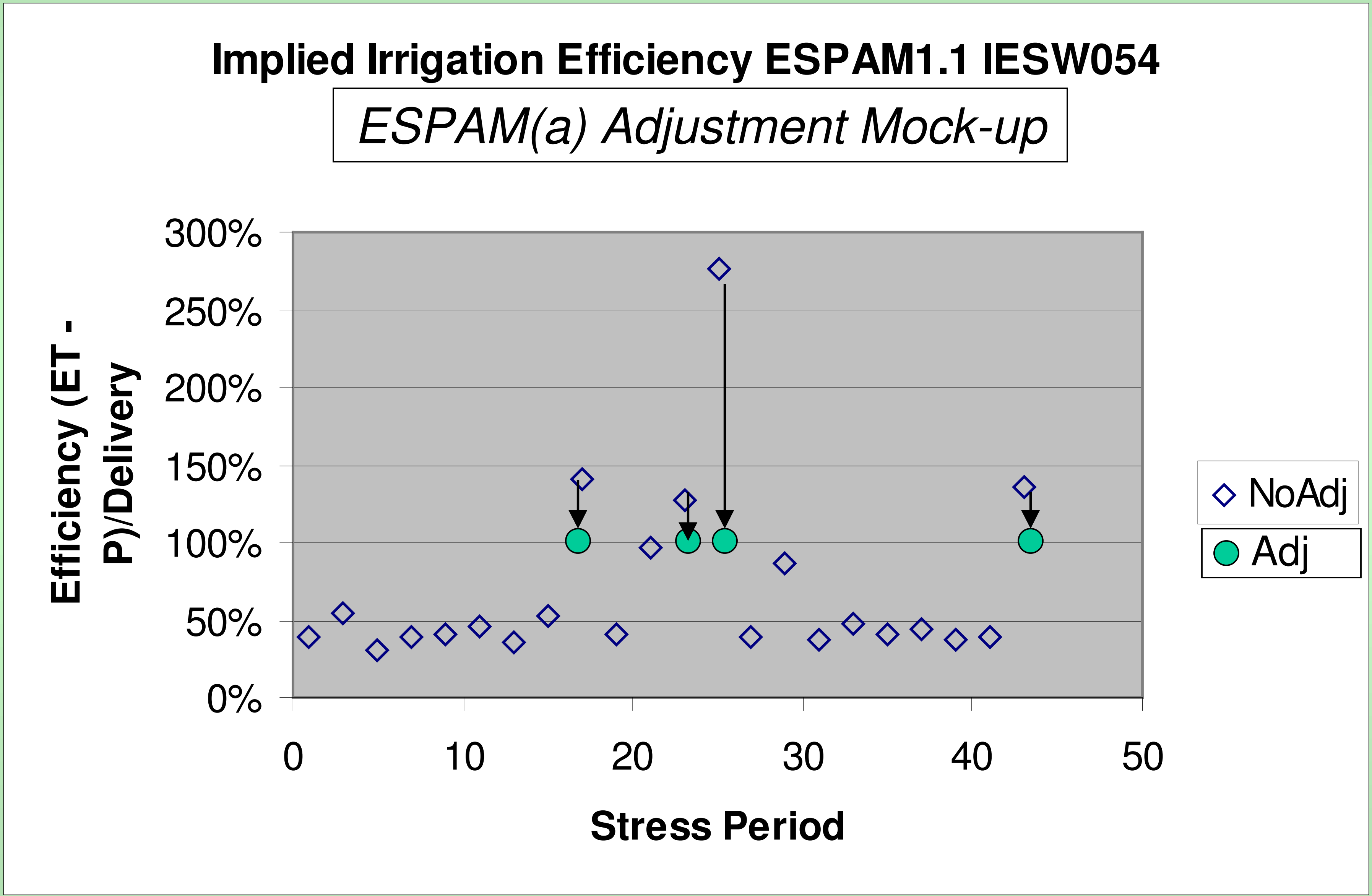


ESPAM(a)
(actually used in ESPAM1.1)

- Ad-hoc adjustment where percolation appeared low
- Only applied to IESW054 in ESPAM1.1
- Could be formalized and made repeatable as

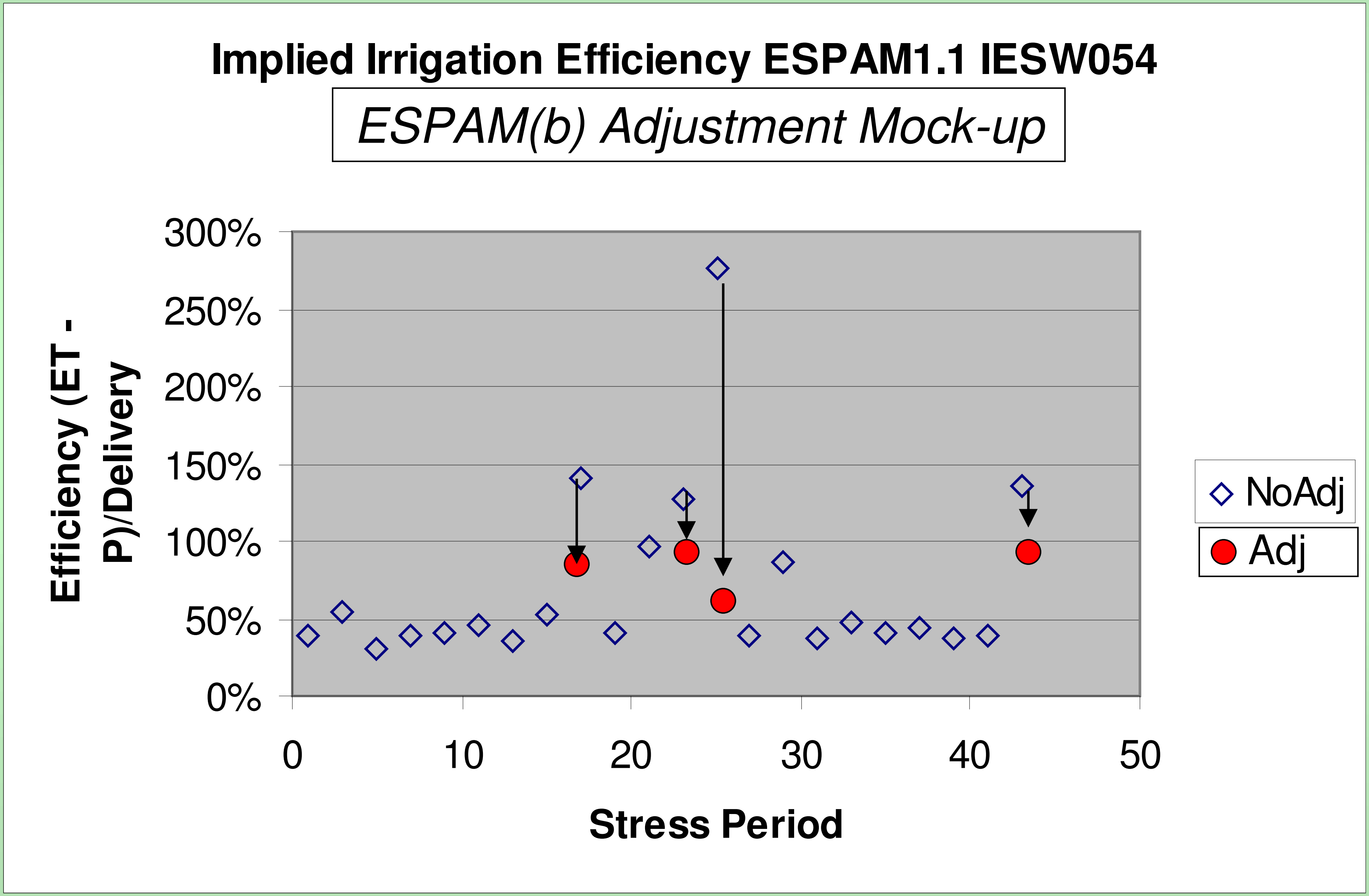
  Perc =
  max(zero,(NetDiv + Pcp - ET*Adj))

(it didn't quite work out that neatly)


Implied Irrigation Efficiency ESPAM1.1 IESW054
ESPAM(a) Adjustment Mock-up
Efficiency (ET - P)/Delivery
300%
250%
200%
150%
100%
50%
0%
0
10
20
30
40
50
Stress Period
NoAdj
Adj

ESPAM(b)
(never used; presented for illustration)

- Perc =
  max(preset value,(NetDiv + Pcp - ET*Adj))



Implied Irrigation Efficiency ESPAM1.1 IESW054
ESPAM(b) Adjustment Mock-up
Efficiency (ET - P)/Delivery
300%
250%
200%
150%
100%
50%
0%
0
10
20
30
40
50
Stress Period
NoAdj
Adj

Martin-Supalla adjustment to ESPAM

Martin-Supalla production function

$$Y = Y_d + (Y_m - Y_d)[1 - (1 - I_r)^{1/\beta}] \quad \ldots \quad (4)$$

in which $\beta = (ET_m - ET_d)/I_m$. The definition of β emerges from the analysis of Martin et al. (1984).

EVALUATION OF IRRIGATION PLANNING DECISIONS

By Derrel L. Martin,[1] James R. Gilley,[2] and Raymond J. Supalla[3]

[3]Prof., Agric. Econ. Dept., Univ. of Nebraska,

Note. Discussion open until July 1, 1989. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on March 16, 1987. This paper is part of the *Journal of Irrigation and Drainage Engineering*, Vol. 115, No. 1, February, 1989. ©ASCE, ISSN 0733-9437/89/0001-0058/$1.00 + $.15 per page. Paper No. 23194.

An efficiency equation can be derived from the Martin-Supalla Equation

$$E = (B/A)\,[1 - (1-A)^{(1/B)}]$$

E = efficiency = (ET - ETd) / I

B = full-yield efficiency = (ETm - ETd) / Im

A = irrigation adequacy = (I / Im)

ETd = ET depth at dryland yield = effective precip

ETm = ET depth at full yield

I = irrigation depth

Im = irrigation depth at full yield

$$E = (B/A)\,[1 - \underbrace{(1-A)}\,^{(1/B)}]$$

how fast depends on initial efficiency

Efficiency depends on:

- Initial efficiency

- Adequacy

Response to adequacy is a non-linear function whose curvature depends on initial efficiency

this term gets bigger as adequacy declines

Proposed Martin-Supalla Adjustment

- If Adequacy <= 1, use Martin-Supalla to define efficiency
  - ET_{red} = precip + net delivery * $efficiency_{Martin-S}$
  - Perc = net delivery + eff. precip - ET_{red}
- Martin-Supalla undefined for Adequacy > 1
  - Assume full ET
    - Perc = net delivery + eff. precip - $ET_{nominal}$* Adj

Fixed Efficiency

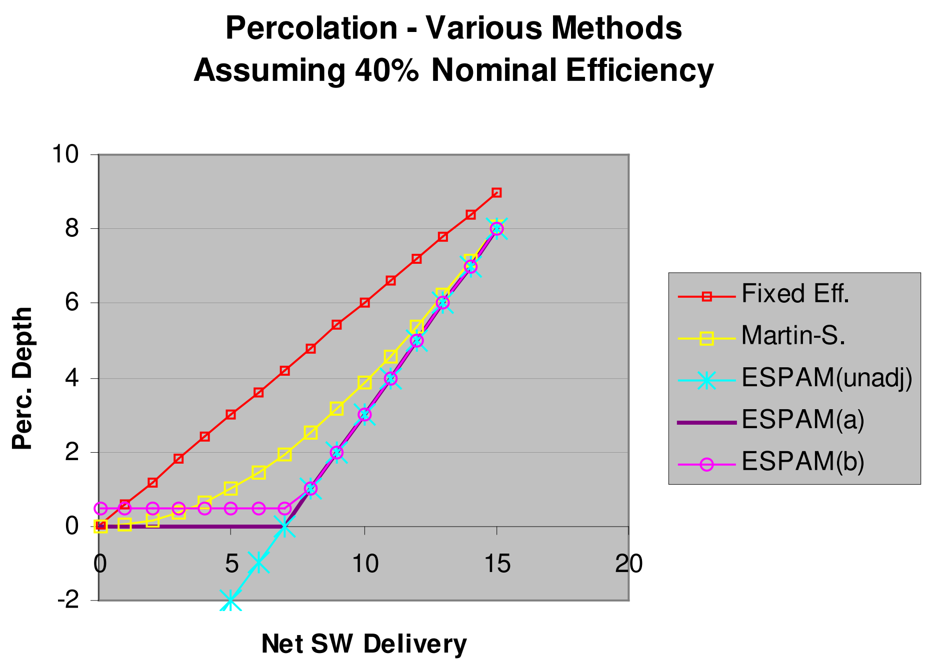
- ET = Precip + (Net Div) * (efficiency)
- Percolation = (Net Div + Precip) - ET

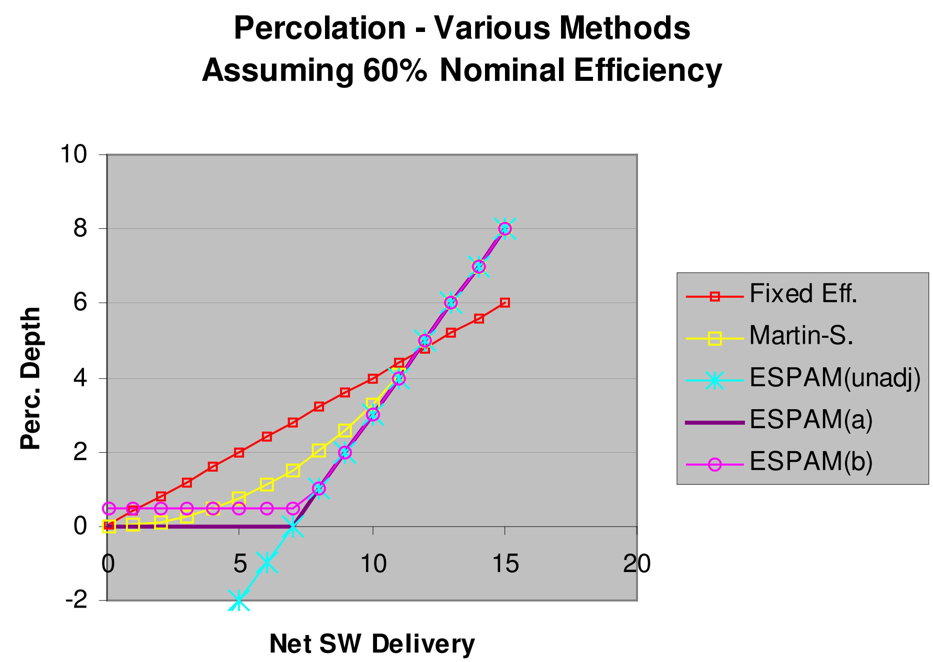
Comparison of Methods

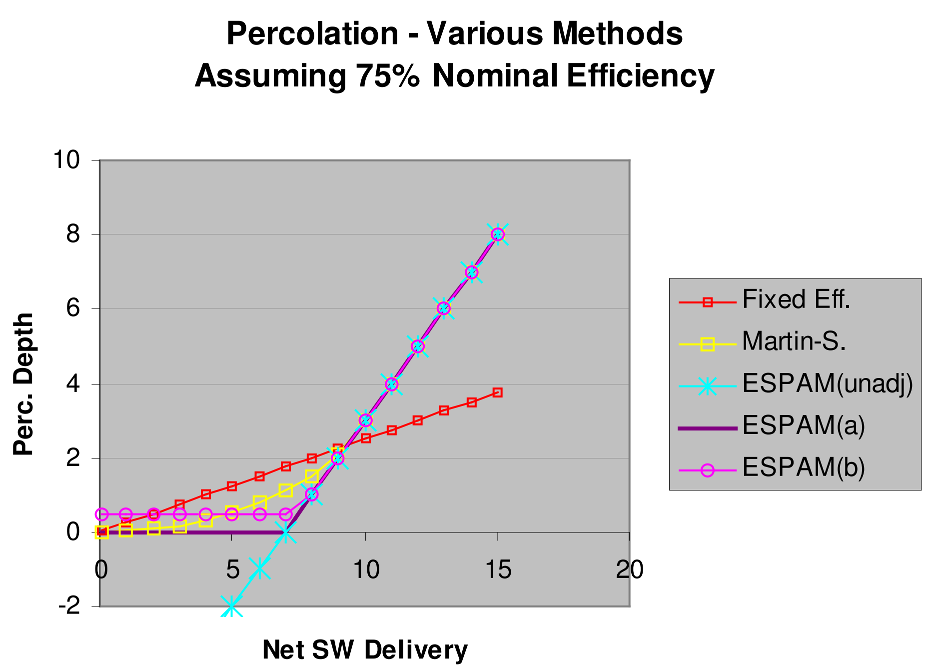
- The value we need for model input:
  - percolation
- Indications of reasonableness:
  - ET depth
  - implied irrigation efficiency
    - (ET supplied from irrigation)/(Irrigation Applied)
    - This sometimes differs from the nominal value upon which calculations were based (for instance, Martin-Supalla achieves nominal efficiency only at exactly the full irrigation depth)

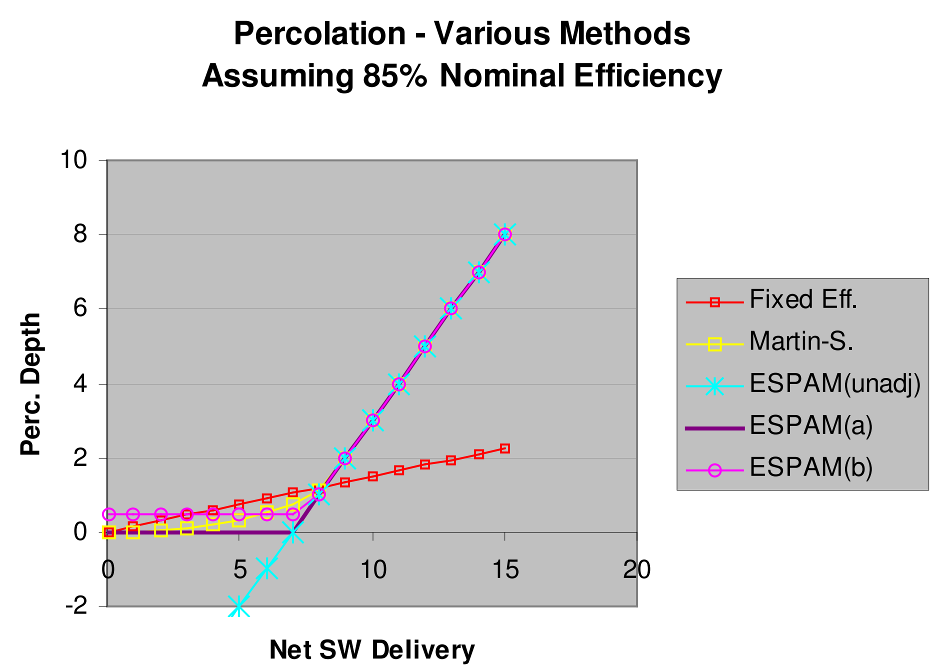
Percolation Expectations

- Should increase w/ application depth
- Lower limit: Zero
- Upper limit: Diversions + Precip


Percolation - Various Methods
Assuming 40% Nominal Efficiency
Perc. Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

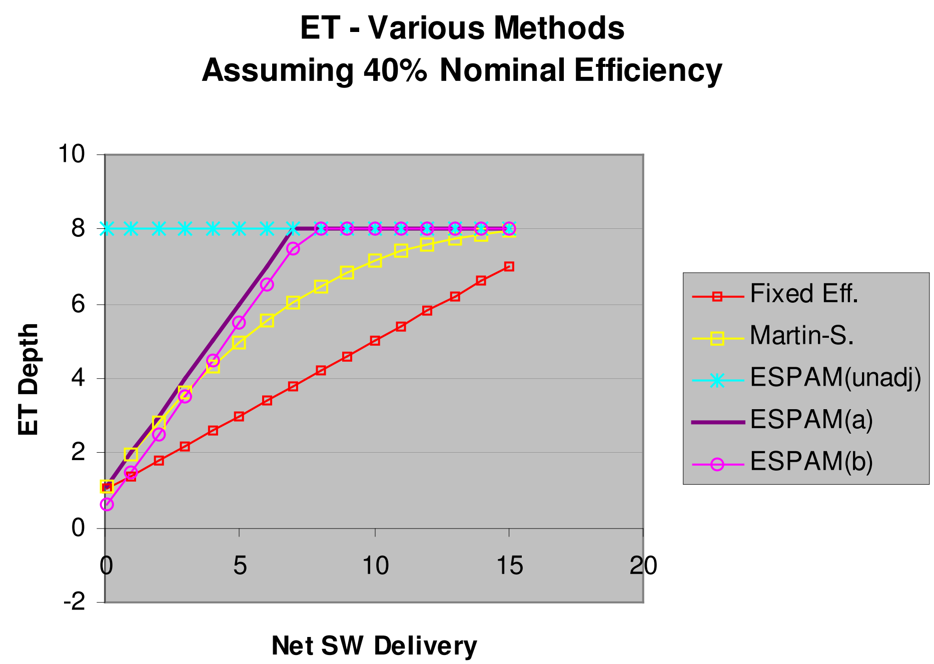

Percolation - Various Methods
Assuming 60% Nominal Efficiency
Perc. Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

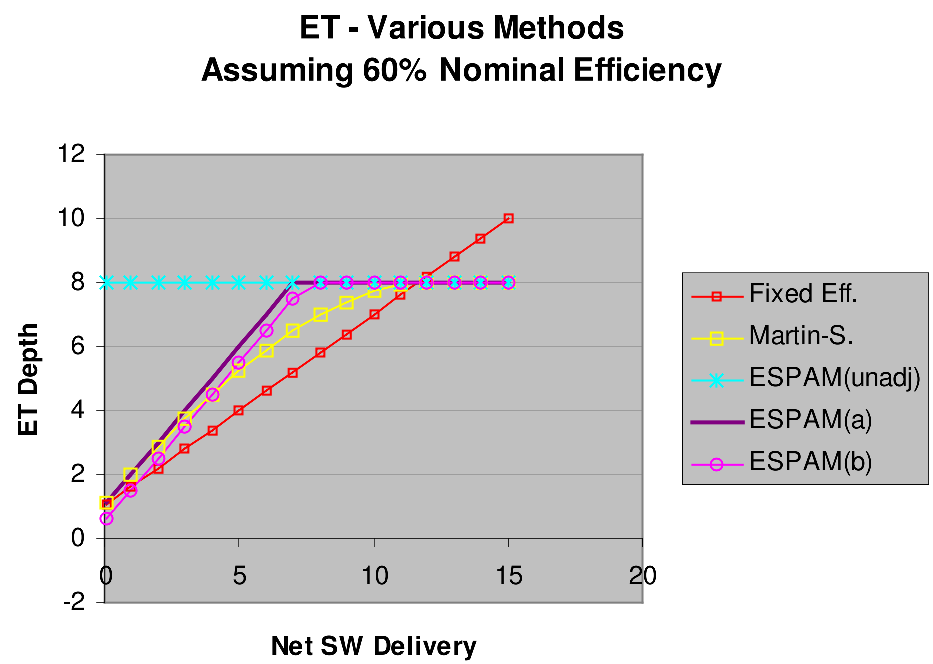

Percolation - Various Methods
Assuming 75% Nominal Efficiency
Perc. Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

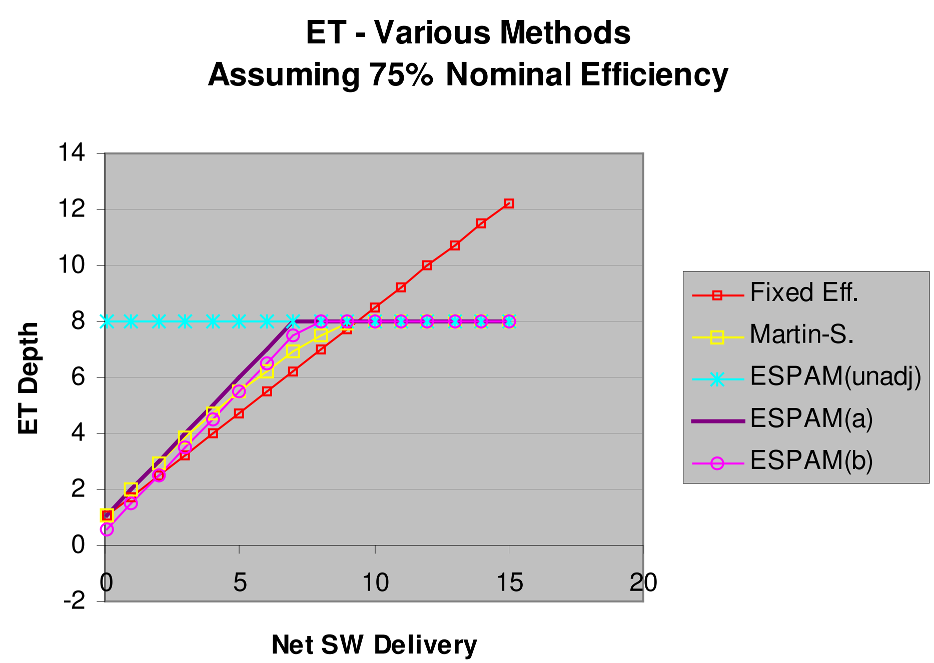

Percolation - Various Methods
Assuming 85% Nominal Efficiency
Perc. Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

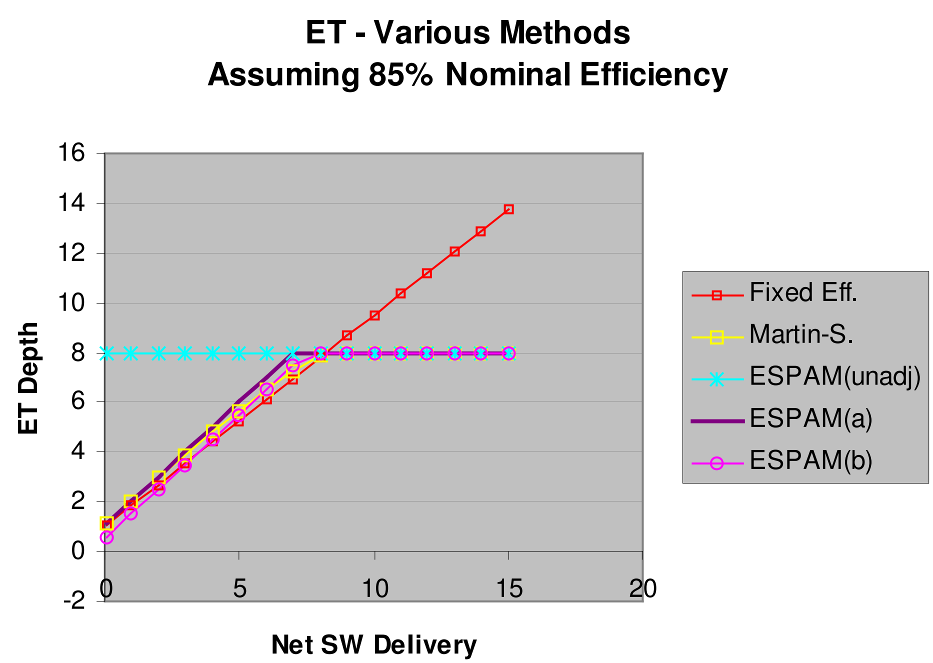
ET Expectations

- Increase w/ increasing application depth
- Lower limit: Zero
- Upper limit
  - min(diversions + precip, energy constraint)


ET - Various Methods
Assuming 40% Nominal Efficiency
ET Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

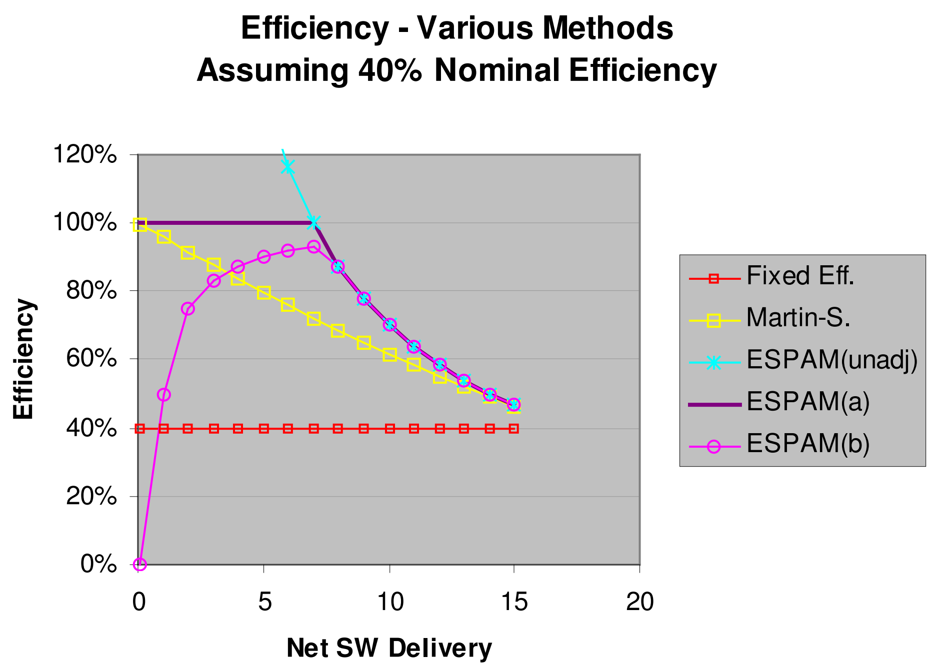

ET - Various Methods
Assuming 60% Nominal Efficiency
ET Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

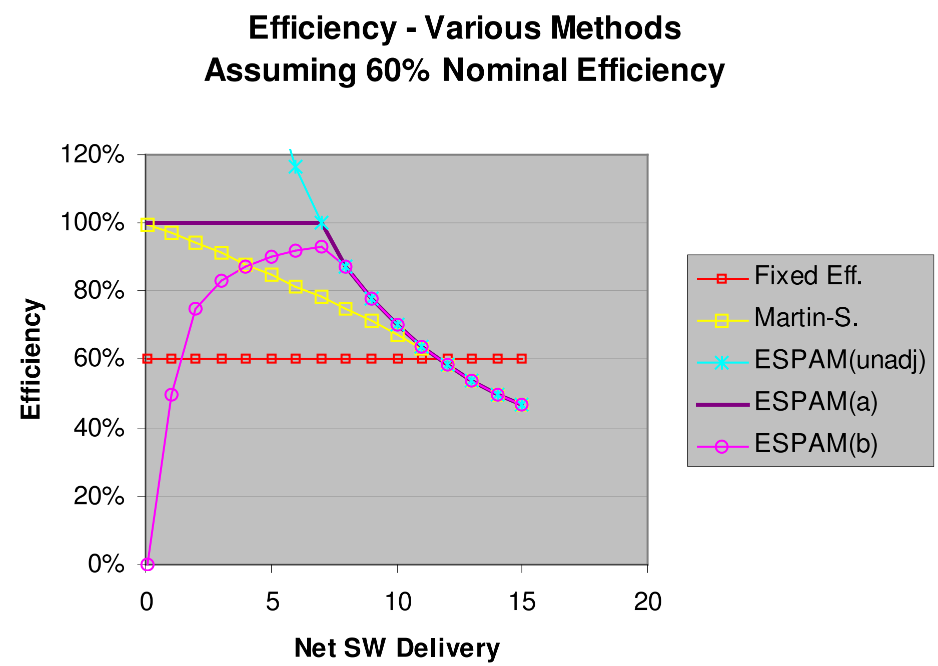

ET - Various Methods
Assuming 75% Nominal Efficiency
ET Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)


ET - Various Methods
Assuming 85% Nominal Efficiency
ET Depth
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

Efficiency Expectations

- Monotonically decreasing w/ increasing application depth
- Lower limit: Zero
- Upper limit: 100%


Efficiency - Various Methods
Assuming 40% Nominal Efficiency
Efficiency
120%
100%
80%
60%
40%
20%
0%
0
5
10
15
20
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)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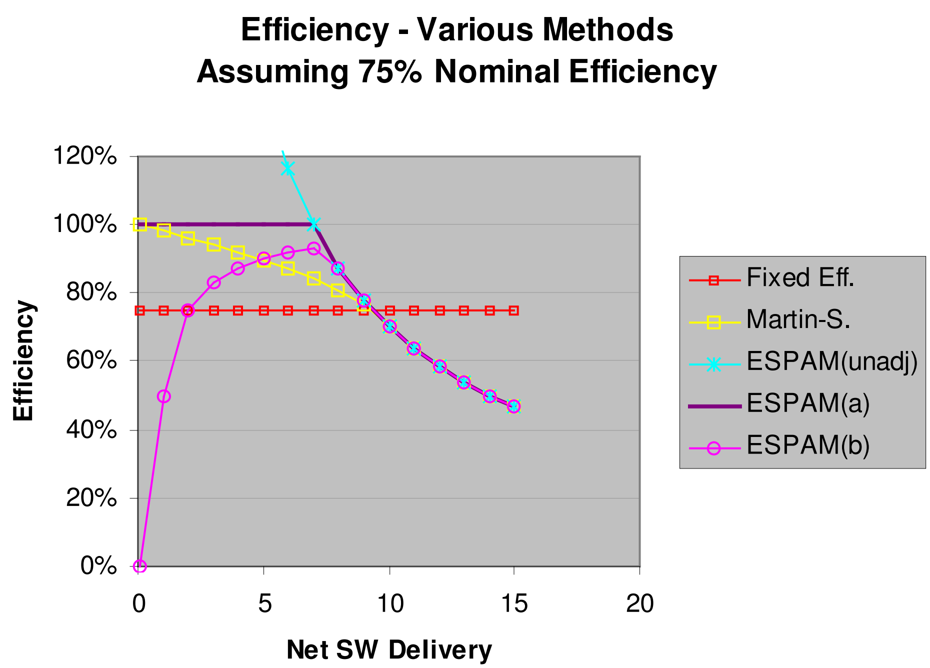
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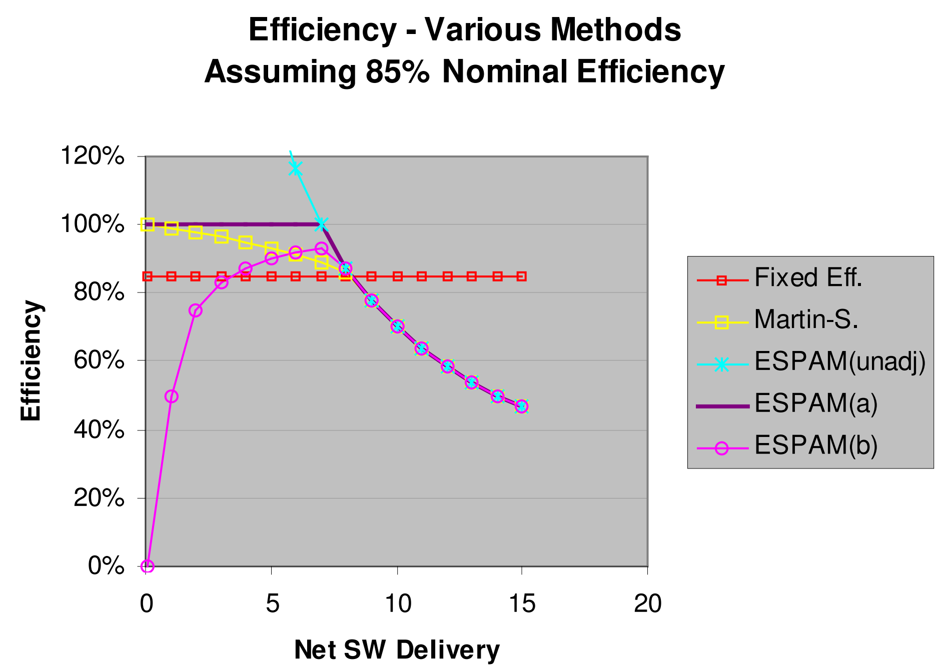
Efficiency - Various Methods
Assuming 85% Nominal Efficiency
Efficiency
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100%
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40%
20%
0%
0
5
10
15
20
Net SW Delivery
Fixed Eff.
Martin-S.
ESPAM(unadj)
ESPAM(a)
ESPAM(b)

Return to Greg's Questions

- 1. "Should the farm-budget calculations be performed seasonally as in the current tool... or should the farm-budget calculations be performed monthly?"
- 2. "What methodology should be used... in the farm budget calculations?"
- 3. "Should the farm budget calculations include... soil moisture storage?"
- 4. "How do mods. to the farm budget calculations relate to... return flows?"

- 1. "Should the farm-budget calculations be performed seasonally... or... monthly?"
  - Proposal:
    - Recharge calculation: monthly, by model cell
      - note that data resolution is not nearly as fine as individual model cells
    - Global adjustment for chronic deficit irrigation: Multiple-year, by entity
    - Adjustment for acute deficits in water-short years: Single irrigation season, by entity

- 2. "What methodology should be used...?"
  - Proposal:
    - Calculate recharge using existing tools/algorithms
    - External adjustment for deficit irrigation
      - ESPAM(a)?
      - ESPAM(b)?
      - ESPAM(Martin-Supalla)?
      - Sullivan?
      - Fixed Efficiency?

- 3. "Should the farm budget calculations include... soil moisture storage?"
  - Proposal:
    - This is a global question affecting all fluxes across land surface, and is tied to vadose-zone storage.
    - Last time we discussed this in ESHMC we agreed to postpone decision until we see if calibration points to a need
    - It may be better to address it globally since it affects multiple water-budget components

- 4. "How do mods. to the farm budget calculations relate to... return flows?"
  - It depends on how adjustments are made, see proposed application to follow
  - Willem's method (to be discussed later) has the advantage of removing sensitivity to uncertainty in returns , by calculating returns as a residual

Outline of Proposed Method

– Stick w/ existing algorithms & recharge tool

– monthly calculation of recharge

– Recharge = **[Div * (1-return frac) + Precip - Canal - ET * Adj]** + ***Deficit Correction***

Recharge Tool

External

(note that canal seepage is also recharge; including it is only a spatial redistribution)

Outline of Proposed Method

- **Adj** based on normal-year calculations and applied on long-term (multi-year) basis
- **Deficit Correction** based on dry-year calculations and applied on a single-season basis
- Several options are available for **Deficit Correction**

Proposed Principles for Manual Adjustment

- First make adjustments that don't change the water budget
  - canal leakage, mixed-source fraction
- If "reasonable" efficiency can't be obtained with "reasonable" adjustments, consider adjustments that do change water budget
  - ET, diversions, return fraction, extra percolation

Proposed Principles for Manual Adjustment (2)

- In each class, honor data in proportion to confidence
  - i.e. minimize variance of (|adjustment|/uncertainty) for all components

Caution & Reality Check

- ET adjustment factors will address chronic deficit on GW-only and mixed-source lands
- We will probably not have the ability to detect acute conditions on these lands
- Any entity with large proportion of mixed-source lands will have too few data to constrain a unique efficiency calculation *(see examples in backup slides)*

Proposed Practical Adjustment Process - Chronic Condition

- Perform assessment on annual basis
- Chart diversions over time
- Make sure ET adjustment factors are calculated in typical diversion years
- For typical diversion years, adjust canal leakage & GW fraction to achieve:
  - W% <= in-field efficiency <= X%
  - Y% <= canal leakage <= Z%
  - A% <= GW Fraction on Mixed <= B%

Proposed Practical Adjustment Process - Chronic (2)

- If this cannot be achieved, check data:
  - Return fraction is wrong?
  - Diversions are wrong?
  - Acres are wrong?
  - Actual canal leakage higher or lower?
  - Actual efficiency very high or low?
    - deep soil, lots of alfalfa, lots of sprinklers, laser-leveled border irrigation, very high pumping lifts
    - low value crops w/ low cost water

Proposed Practical Adjustment Process - Chronic (3)

- If nothing is found, manually change ET adjustment factor
  - this is easy to do
  - it only changes on-farm water budget, not river-gains water budget
- If change in ET adjustment factor has to be too severe (|old - new| > C), consider also **tinkering w/ return fractions**
  - this is also easy to do but it affects river gains

Proposed Practical Adjustment Process - Chronic (4)

- The outcome of this process will be a suite of adjustment factor, mixed-source fraction, canal leakage and return fraction that imply "reasonable" irrigation efficiency in "normal" water years, for each entity
  - Economic theory: Chronic water stress will result in abandonment of acres or acquisition of supplemental supplies; very high efficiencies will not persist except w/ high marginal cost of irrigation

Proposed Practical Adjustment Process - Acute Condition

- For years with short deliveries, calculate input needed for selected algorithm
  - ESPAM(a), Sullivan: Perc. depth
  - ESPAM(Martin-S): Adequacy
  - etc.
- Using selected algorithm, calculated needed adjustment
- Apply needed adjustments using fixed-point capability of recharge tool

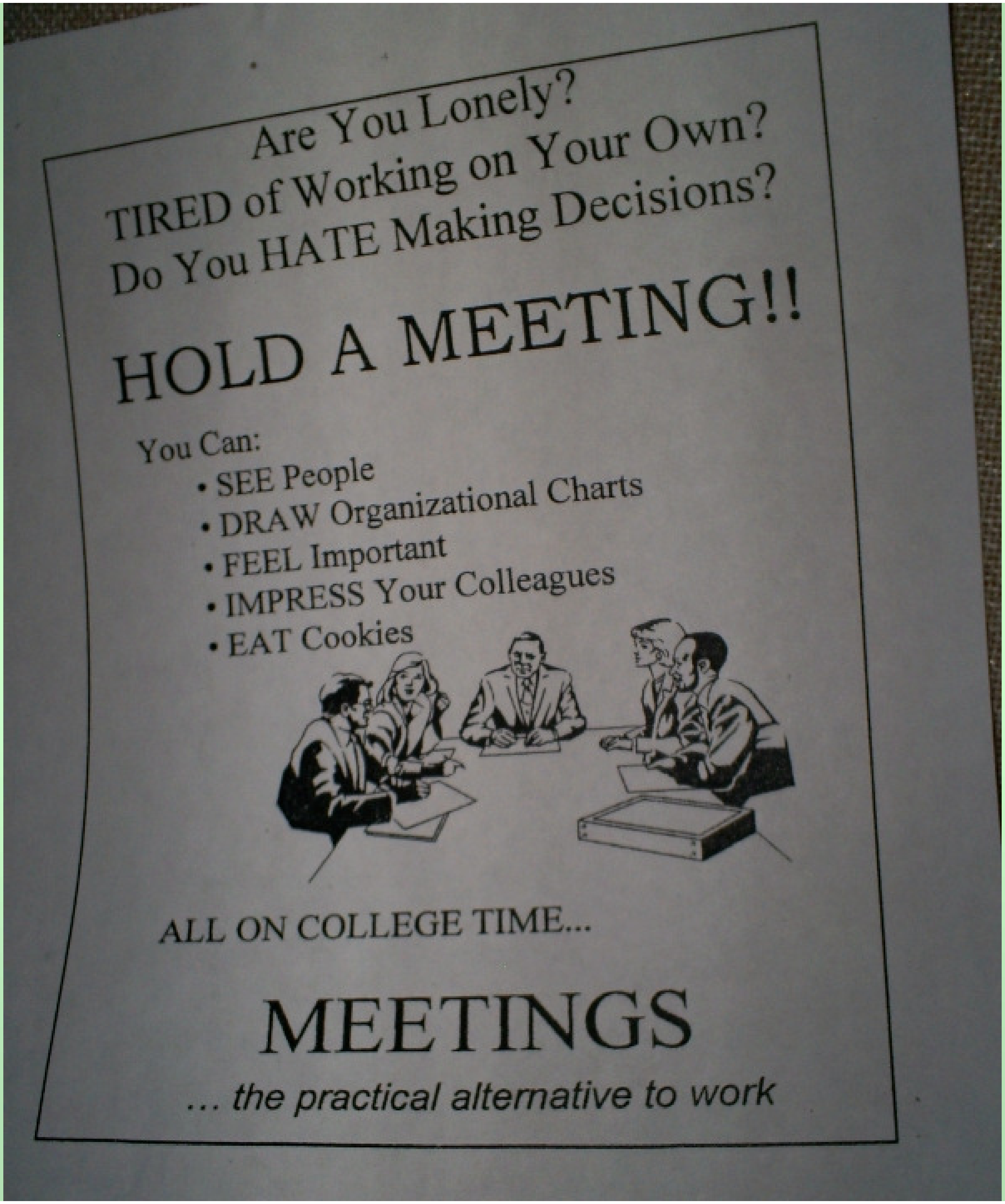
Selection of Algorithm

- Any of the algorithms presented here could be adapted
  - Based on percolation depth, reject ESPAM w/o adjustment
  - Based on max ET, reject fixed efficiency
  - Based on increasing efficiency w/ increasing diversions, reject ESPAM(b)

- Remaining Candidates:
  - ESPAM(a)

    Perc = max(zero,(NetDiv + Pcp - ET))
  - Sullivan
  - ESPAM(Martin-Supalla)

- Input from ESHMC?



Are You Lonely?
TIRED of Working on Your Own?
Do You HATE Making Decisions?
HOLD A MEETING!!
You Can:
• SEE People
• DRAW Organizational Charts
• FEEL Important
• IMPRESS Your Colleagues
• EAT Cookies
ALL ON COLLEGE TIME...
MEETINGS
... the practical alternative to work

Backup Slides: Derivation

$$Y = Y_d + (Y_m - Y_d)\left[1 - \left(1 - \left(1 - I/I_m\right)^{(1/B)}\right]\right. -$$

remember B = irr. efficiency @ max yield

$$= (ET_m - ET_d)/I_m$$

define A = irrigation adequacy

$$= I/I_M$$

$$Y = Y_d + (Y_m - Y_d)\left[1 - (1 - A)^{(1/B)}\right]$$

(sorry about the plodding but I'm a plodder)

assume linear ET production function
and define $K = Y/ET$ so that $Y = K\,ET$

$$Y_d = K\,ET_d$$

$$Y_m = K\,ET_m$$

$$K\,ET = K\,ET_d + (K\,ET_m - K\,ET_d)\left[1 - (1-A)^{(1/B)}\right]$$

Note that linear ET production function is implicit in original equation; to see this apply B = 1 (100% irrigation efficiency).

divide by K

$$ET = ETd + (ETm - ETd)\left[1 - (1-A)^{(C/B)}\right]$$

Subtract ETd from both sides & simplify

$$ET - ETd = (ETm - ETd)\left[1 - (1-A)^{(C/B)}\right]$$

2

divide both sides by I

$$\frac{ET - ETd}{I} = \left(\frac{ETm - ETd}{I}\right)\left[1 - (1-A)^{(1/B)}\right]$$

multiply right side by $\frac{Im}{Im} = 1$

$$\frac{ET - ETd}{I} = \left(\frac{ETm - ETd}{I}\right)\frac{Im}{Im}\left[1 - (1-A)^{(1/B)}\right]$$

rearrange denominator of right side

$$\frac{ET - ETd}{I} = \left(\frac{ETm - ETd}{Im}\right)\left(\frac{Im}{I}\right)\left[1 - (1-A)^{(1/B)}\right]$$

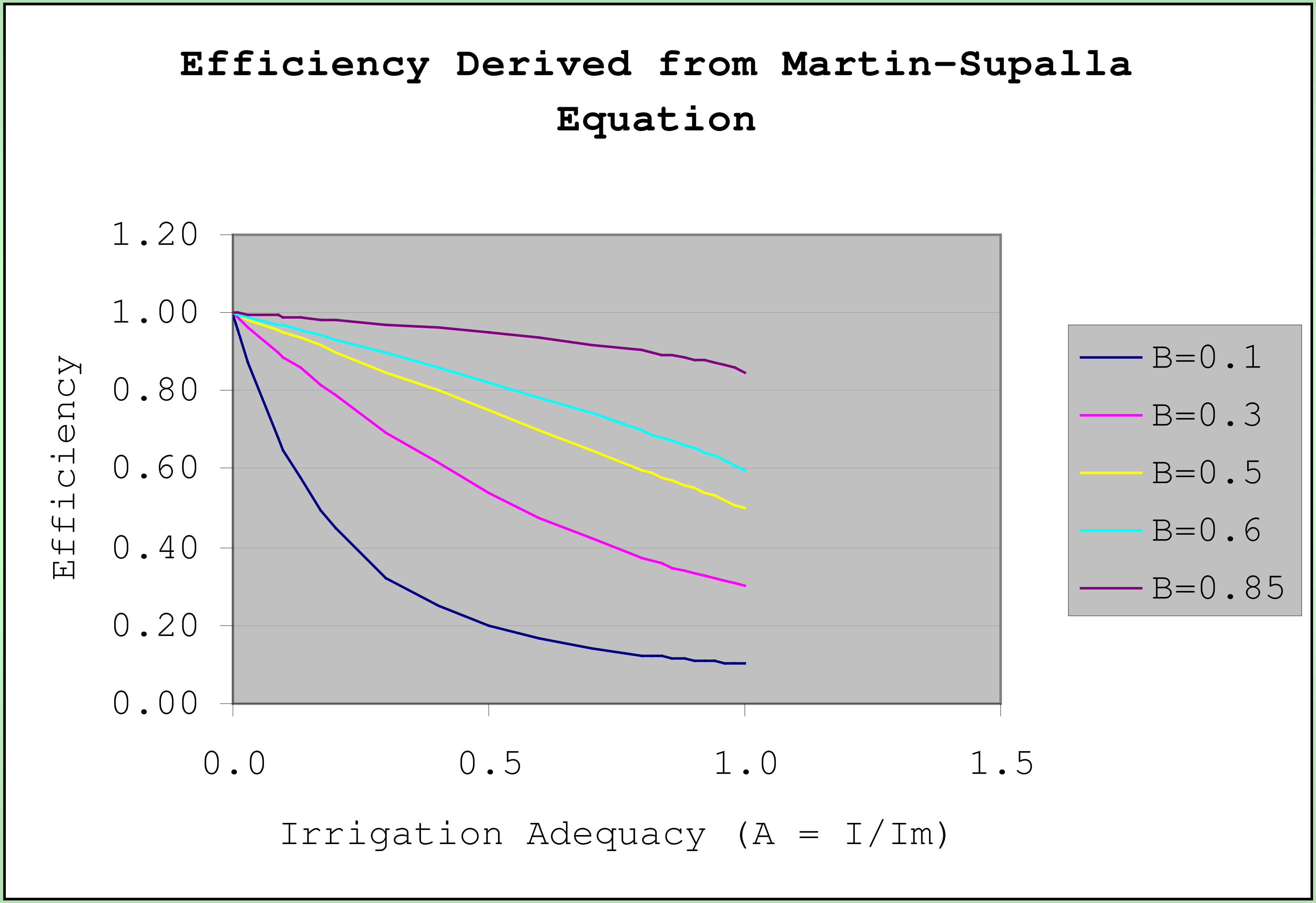
Substitute $B = (ETm - ETd)/Im$

and $A = (I/Im)$

define $\mathcal{E}$ = efficiency

$= (ET - ETd)/I$

$$\boxed{\mathcal{E} = \frac{B}{A}\left[1 - (1-A)^{(1/B)}\right]}$$


Efficiency Derived from Martin-Supalla Equation
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Efficiency
0.0
0.5
1.0
1.5
Irrigation Adequacy (A = I/Im)
B=0.1
B=0.3
B=0.5
B=0.6
B=0.85

Backup Slides: Implications of Uncertainty in Canal Leakage & Returns

- Facts
  - Diversions = 10,000
  - Scanty returns data range from 5% to 15%
  - 2,500 acres SW-only
  - 2,500 acres Mixed-src
  - Nominal ET = 2 feet
  - Effective Precipitation 0.6 feet
- Assumptions
  - GW fraction on mixed-source is 10%
  - Canal leakage is 20%
  - Return fraction is 10%
  - Efficiency = (ET - Precip)/(SW depth)

Fun With Math

- Returns = 10,000 * 10% = 1,000
- Canal Leakage = 10,000 * 20% = 2,000
- Net diversion vol = 10,000 - (1,000 + 2,000)
  = 7,000
- SW acres = 2,500 + [2,500 * (1 - 0.1)]
  = 4,750
- SW depth = 7,000 / 4,750 = 1.5 feet
- Efficiency = (2.0 - 0.6) / 1.5 = **93**%

Fun With Math (2)

- Returns = 10,000 * 10% = 1,000
- Canal Leakage = 10,000 * **10**% = 1,000
- Net diversion vol = 10,000 - (1,000 + 1,000) = 8,000
- SW acres = 2,500 + [2,500 * (1 - **0.3**)] = 4,250
- SW depth = 8,000 / 4,250 = 1.9 feet
- Efficiency = (2.0 - 0.6) / 1.9 = **74%**

But wait, there's more!

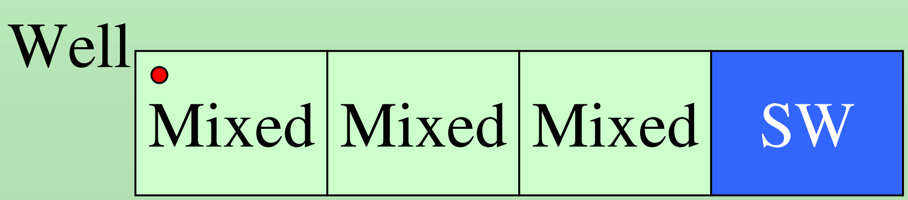
- Returns = 10,000 * 10% = 1,000
- Canal Leakage = 10,000 * **10**% = 1,000
- Net diversion vol = 10,000 - (1,000 + 1,000)
  = 8,000
- SW acres = 2,500 + [2,500 * (1 - **0.5**)]
  = 3,750
- SW depth = 8,000 / 3,750 = 2.1 feet
- Efficiency = (2.0 - 0.6) / 2.1 = **67%**

We made implied efficiency range from 67% to 93% by adjusting canal seepage and GW fraction ***within the bounds of our knowledge.***
We did this ***without*** *affecting net recharge or river gains.*

Backup Slides: Effect on Water Budget of GW Fraction on Mixed-Source Lands

Hypothetical Facts

- 30 acres mixed-source, 10 acres SW-only
- Net SW diversions = 40 acre feet
- nominal ET = 80 acre feet = 2 feet depth
- Precip = 40 acre feet = 1 foot depth
- Limited knowledge of mixed-source lands
- No data on GW pumpage



Three Algorithms Considered

- No adjustment
- Adjust ET to honor efficiency constraint
- Adjust net diversions to honor efficiency constraint
  - adjust gross diversions, or;
  - adjust return-flow fraction

I. No Adjustment for Irr. Efficiency

- Diversion depth =
  (Div Vol) / (SW Acres + Mixed (1-frac))
- SW-only Recharge =
  Acres * (Div + Precip - ET)
- SW on mixed-source =
  (Acres * (1-frac)) * (Div + Precip - ET)
- GW on mixed-source =
  (Acres * frac) * (Precip - ET)
- Implied Efficiency =
  (Precip - ET) / (Diversion Depth)

Assume 90% GW on mixed-source parcels

- SW depth = (40 acre ft) / (30 * 0.1 + 10)
  = 3.08 feet
- SW-only
  10 (3.08 + 1 - 2) = 20.8
- SW on mixed
  30 (0.1) (3.08 + 1 -2) = 6.2
- GW on mixed
  30 (0.9) (1-2) = -27
- Implied efficiency
  (2 - 1) / 3.08 = 32%

Net Recharge Zero

Assume 50% GW on mixed-source parcels

- SW depth = (40 acre ft) / (30 * 0.5 + 10)
  = 1.6 feet
- SW-only
  10 (1.6 + 1 - 2) = 6
- SW on mixed
  30 (0.5) (1.6 + 1 -2) = 9
- GW on mixed
  30 (0.5) (1-2) = -15
- Implied efficiency
  (2 - 1) / 1.6 = 63%

Net Recharge Zero

Assume 10% GW on mixed-source parcels

- SW depth = (40 acre ft) / (30 * 0.9 + 10)
  = 1.08 feet
- SW-only
  10 (1.08 + 1 - 2) = 0.8
- SW on mixed
  30 (0.9) (1.08 + 1 -2) = 2.2
- GW on mixed
  30 (0.1) (1-2) = -3

Net Recharge Zero

- Implied efficiency
  (2 - 1) / 1.08 = 93%

Implications

- Assignment of GW fraction does not affect water budget
  - spatial distribution *within the entity* is affected
  - precise knowledge of fraction is not needed
- Water budget depends on correct Diversions, Returns and ET

IIa. Constrain ET by Irr. Efficiency

- Assume 70% irr. efficiency
- Adjust ET as needed to honor constraint

  ET = (Div * Efficiency) + Precip

Assume 90% GW on mixed-source parcels

- SW depth = (40 acre ft) / (30 * 0.1 + 10)
  = 3.08 feet
- (3.08 * 0.7) + 1 =3.16 ft ET = 158% of nominal
- SW-only
  10 (3.08 + 1 - 3.16) = 9.2
- SW on mixed
  30 (0.1) (3.08 + 1 -3.16) = 2.8
- GW on mixed
  30 (0.9) (1-3.16) = -58

Net Recharge -46

Assume 50% GW on mixed-source parcels

- SW depth = (40 acre ft) / (30 * 0.5 + 10)
  = 1.6 feet
- (1.6 * 0.7) + 1 =2.12 ft ET = 106% of nominal
- SW-only
  10 (1.6 + 1 - 2.12) = 4.8
- SW on mixed
  30 (0.5) (1.6 + 1 -2.12) = 7.2
- GW on mixed
  30 (0.5) (1-2.12) = -17

Net Recharge
-5

Assume 10% GW on mixed-source parcels

- SW depth = (40 acre ft) / (30 * 0.9 + 10)
  = 1.08 feet
- (1.08 * 0.7) + 1 =1.76 ft ET = 88% of nominal
- SW-only
  10 (1.08 + 1 - 1.76) = 3.2
- SW on mixed
  30 (0.9) (1.08 + 1 -1.76) = 8.6
- GW on mixed
  30 (0.1) (1-1.76) = -2.3

Net Recharge +9.5

Implications

- This approach requires that when SW depth is low, users will not compensate by applying additional GW
  (that is the only way you can get reduced ET on the mixed-source acres)
- ET varies significantly from nominal
- Water budget and spatial distribution are dependent on correct representation of mixed-source lands & GW fraction.

IIb. Constrain Diversions by Irr. Efficiency

- Assume 70% irr. efficiency
- Adjust Net Diversions as needed to honor constraint

  Div Depth = (ET - Precip) / Efficiency

  Div Vol = Depth * Acres
- Net diversions can be adjusted by changing gross diversions or by changing return fraction

Assume 90% GW on mixed-source parcels

- SW diversion depth = (2 - 1) / 0.70 = 1.43 feet
- SW recharge = 1.43 + 1 - 2 = 0.43 feet

- SW only
  10 * 0.43 = 4.3
- SW on mixed
  (30 * 0.1) * 0.43 = 1.3
- GW on mixed
  (30 * 0.9) * (1-2) = -27

Net Recharge -21

- Implied SW Volume
  [10 + (30 * 0.1)] * 1.43 = 19 (vs. data of 40)

Assume 50% GW on mixed-source parcels

- SW diversion depth = (2 - 1) / 0.70 = 1.43 feet
- SW recharge = 1.43 + 1 - 2 = 0.43 feet

- SW only
  10 * 0.43 = 4.3
- SW on mixed
  (30 * 0.5) * 0.43 = 6.5
- GW on mixed
  (30 * 0.5) * (1-2) = -15

Net Recharge -4.2

- Implied SW Volume
  [10 + (30 * 0.5)] * 1.43 = 36 (vs. data of 40)

Assume 10% GW on mixed-source parcels

- SW diversion depth = (2 - 1) / 0.70 = 1.43 feet
- SW recharge = 1.43 + 1 - 2 = 0.43 feet

- SW only
  10 * 0.43 = 4.3
- SW on mixed
  (30 * 0.9) * 0.43 = 11.6
- GW on mixed
  (30 * 0.1) * (1-2) = -3
- Implied SW Volume
  [10 + (30 * 0.9)] * 1.43 = 53 (vs. data of 40)

Net Recharge 13

Implications

- Net diversions vary significantly from data
- Water budget and spatial distribution are dependent on correct representation of mixed-source lands & GW fraction.

Summary Table

DIV / *Rech*

	90% GW	50% GW	10% GW
I. No Adjustment	**40** / *Zero*	**40** / *Zero*	**40** / *Zero*
II. Adjust ET	**40** / *-46*	**40** / *-5*	**40** / *+9.5*
II. Adjust Net Diversions	**19** / *-21*	**36** / *-4.2*	**53** / *+13*

Backup Slides: Literature Excerpts

Agricultural Water Management, 3 (1980) 53—64 53
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CROP PRODUCTION FUNCTIONS AND THE ALLOCATION AND USE OF IRRIGATION WATER

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(Accepted 18 October 1979)

ABSTRACT

Barrett, J.W.H. and Skogerboe, G.V., 1980. Crop production functions and the allocation an

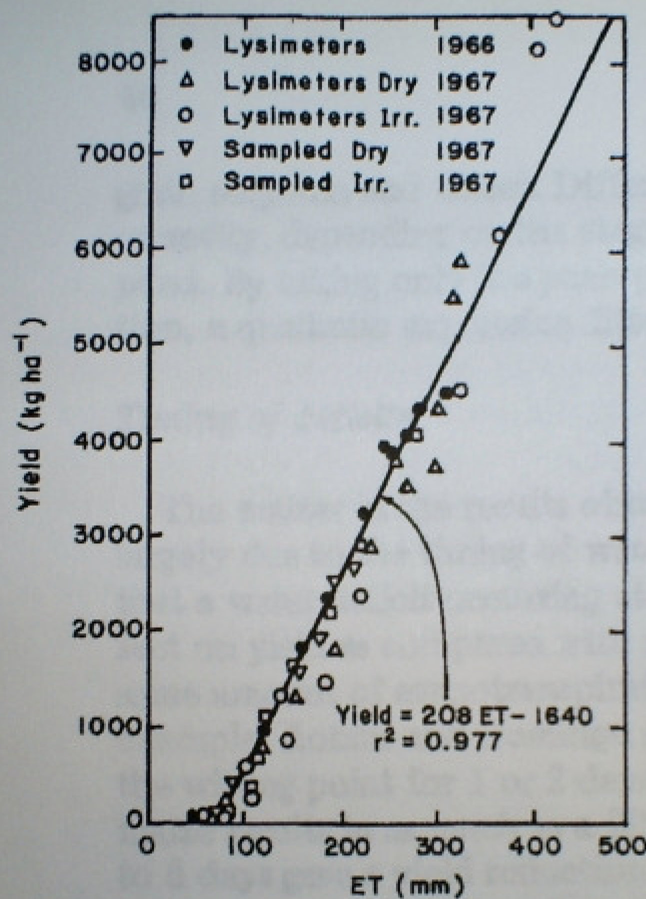
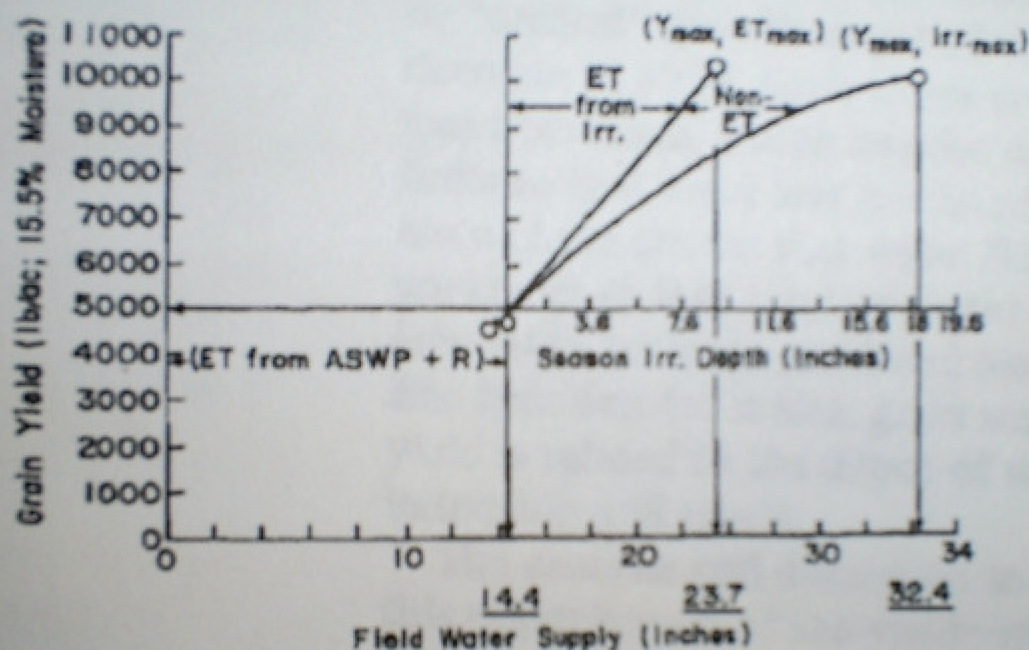


Fig.1. Relation of cumulative dry matter yield of grain sorghum to evapotranspira
Hanks et al., 1969).

A linear relationship between both dry matter and grain yield and e

the curvilinear nature of the function may be due to a portion o water being unavailable for crop evapotranspiration (e.g., deep p losses).



Legend:

ASWP = Depth of Available Soil Water at Planting

R = Rainfall Depth

Irr. = Water Supplied by Irrigation

FWS = Field Water Supply

Chapter 12

Water Use Efficiency in Sustainable Agricultural Systems

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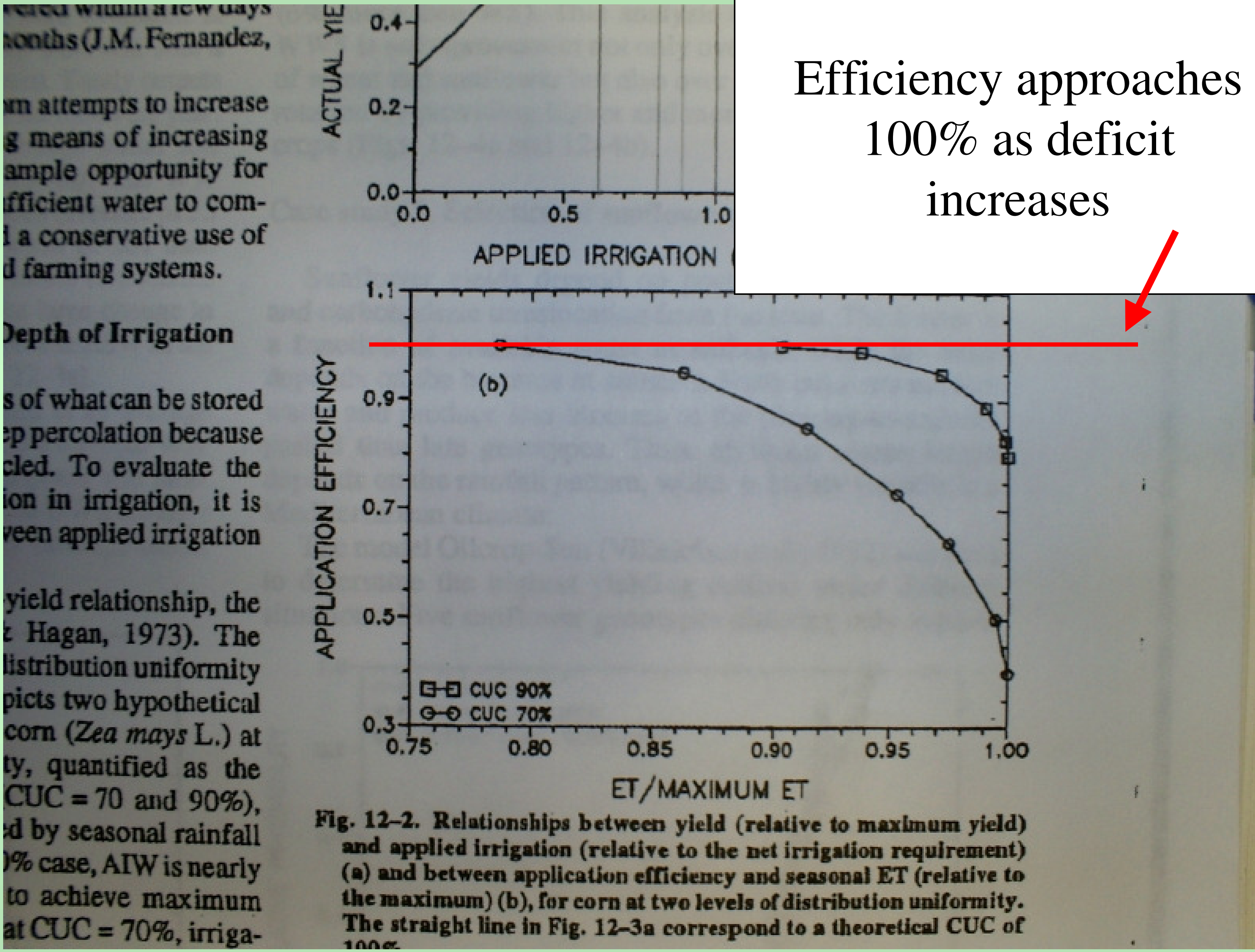

Efficiency approaches 100% as deficit increases

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doi:10.1016/j.biosystemseng.2003.11.008
SW—Soil and Water

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The Effects of Irrigation Efficiency and Uniformity Coefficient on Relative Y and Profit for Deficit Irrigation

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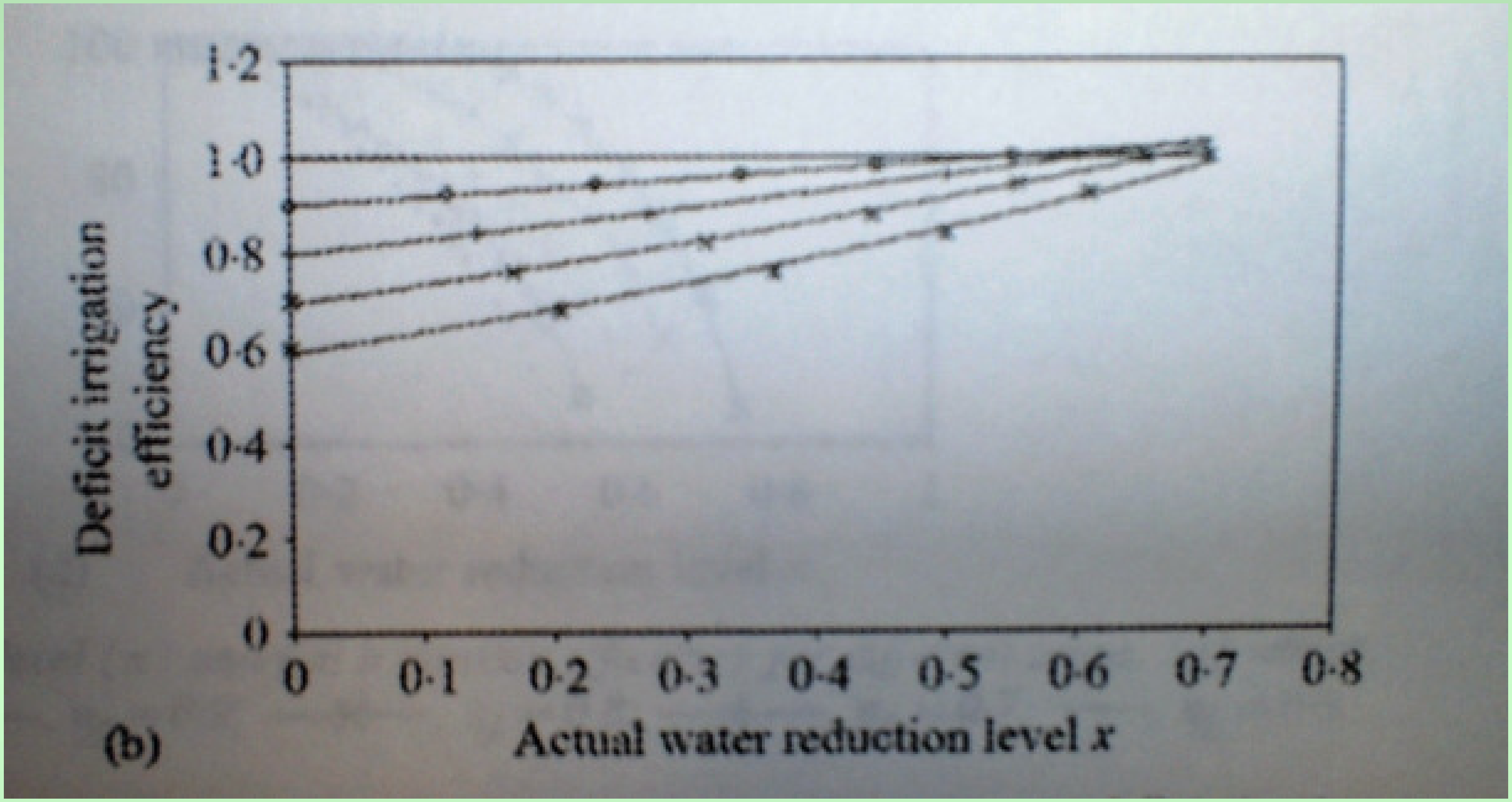
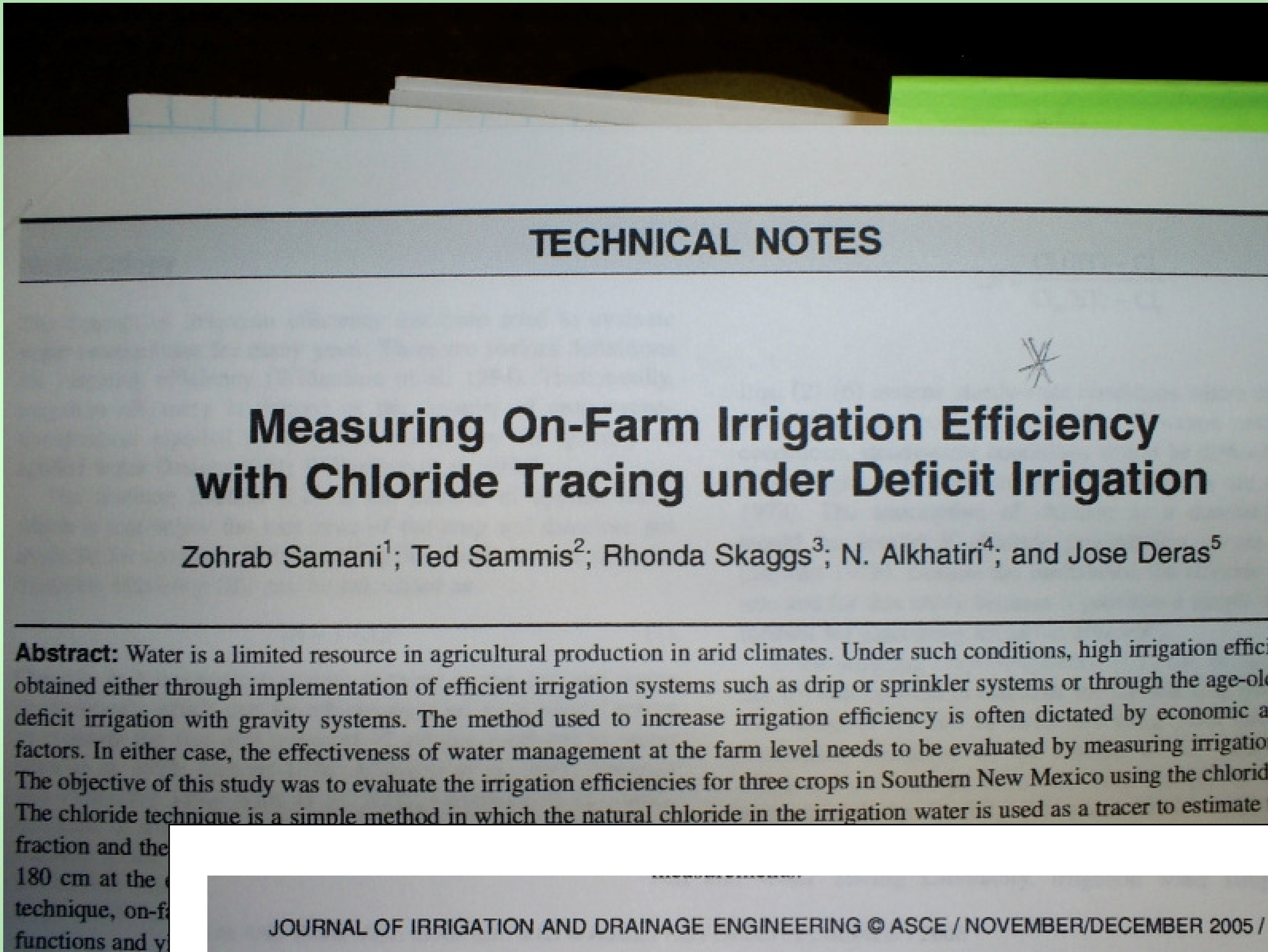
To avoid constructing expensive hydraulic structures for implementing new water resources, a deficit irrigatio project may be designed to optimise the use of the available water resources. Previously, irrigation efficienc and uniformity coefficient have not been considered quantitatively. In fact, efficiency is a very significant facto in optimisation analysis, and the potential for increasing irrigation efficiency is one of the key reasons fo deficit irrigation. In this paper, the influences of irrigation efficiency under full irrigation condition η_f on th performance of deficit irrigation, and the effects of deficit irrigation on improving the irrigation efficienc



Different lines represent different full-irrigation efficiencies, as defined by "zero reduction" intercept on the vertical (efficiency) axis.



TECHNICAL NOTES

Measuring On-Farm Irrigation Efficiency with Chloride Tracing under Deficit Irrigation

Zohrab Samani[1]; Ted Sammis[2]; Rhonda Skaggs[3]; N. Alkhatiri[4]; and Jose Deras[5]

Abstract: Water is a limited resource in agricultural production in arid climates. Under such conditions, high irrigation efficie
obtained either through implementation of efficient irrigation systems such as drip or sprinkler systems or through the age-old
deficit irrigation with gravity systems. The method used to increase irrigation efficiency is often dictated by economic an
factors. In either case, the effectiveness of water management at the farm level needs to be evaluated by measuring irrigation
The objective of this study was to evaluate the irrigation efficiencies for three crops in Southern New Mexico using the chloride
The chloride technique is a simple method in which the natural chloride in the irrigation water is used as a tracer to estimate t
fraction and the
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functions and y

Table 2. Results of Chloride Analysis for Alfalfa for 3 Years

Field	Soil type	Year	Yield (t/ha)	Relative yield	ET (estimated) (cm)	Leaching factor (%)	Irrigation efficiency (estimated) (%)
A-1	Loam	1996	20.78	0.7	172	2	98
A-1	Loam	1997	17.97	0.6	148	6	94
A-1	Loam	1998	18.0	0.6	149	4	96
A-2	Clay	1996	22.46	0.7	186	13	87
A-2	Clay	1997	20.21	0.6	167	11	89
A-2	Clay	1998	18.42	0.6	152	5	95

and ten sites were used in the evaluation. The results showed that, contrary to conventional belief, high on-farm irrigation efficiencies can be obtained using surface irrigation. Irrigation efficiencies ranged from 83 to 98%. The high irrigation efficiencies in the area were mainly due to deficit irrigation, with the exception of one field, where a high irrigation efficiency was obtained due to use of high flow turnout, laser leveled field, and irrigation scheduling. The chloride technique is subject to